

*Venture EVI-2*



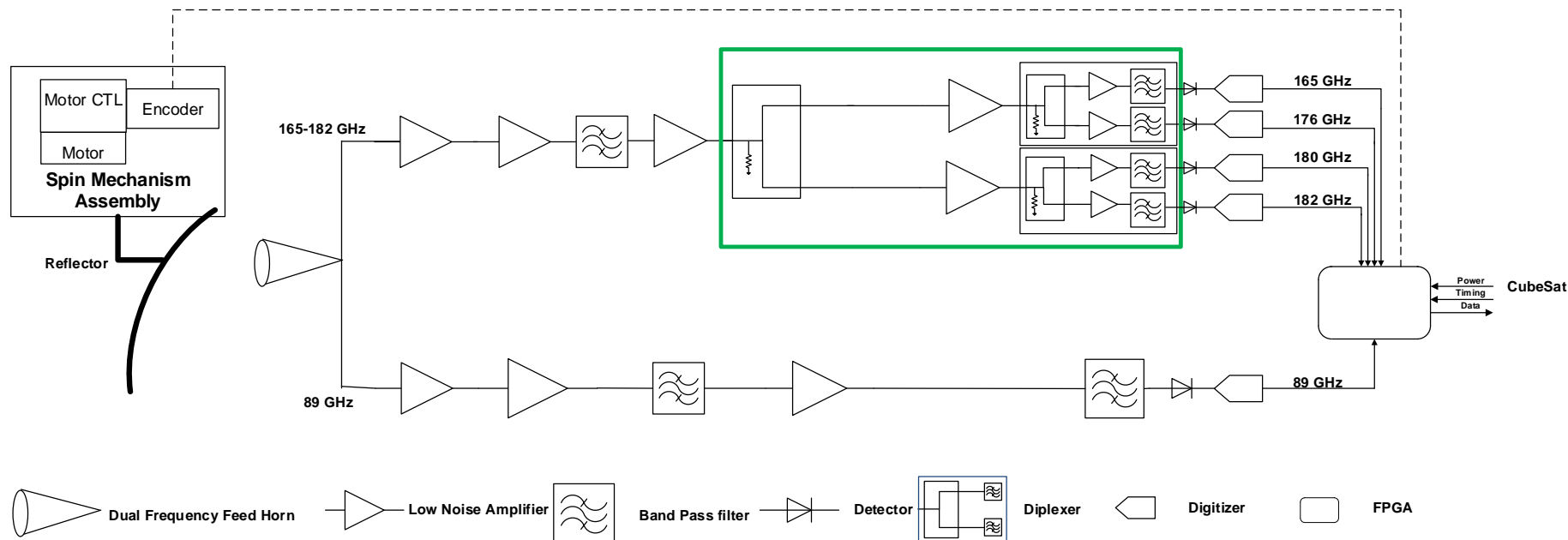
# TEMPEST-D Millimeter-Wave Radiometers

**JPL Team: Todd Gaier, Sharmila Padmanabhan, Boon Lim, Alan Tanner, Shannon Brown, Robert Stachnik, Richard Cofield, Gabriella Seal, Robert Jarnot, Cate Heneghan,**

**CSU Team: Steven Reising, Wes Berg Christian Kummerow, V. Chandrasekar,**

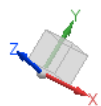
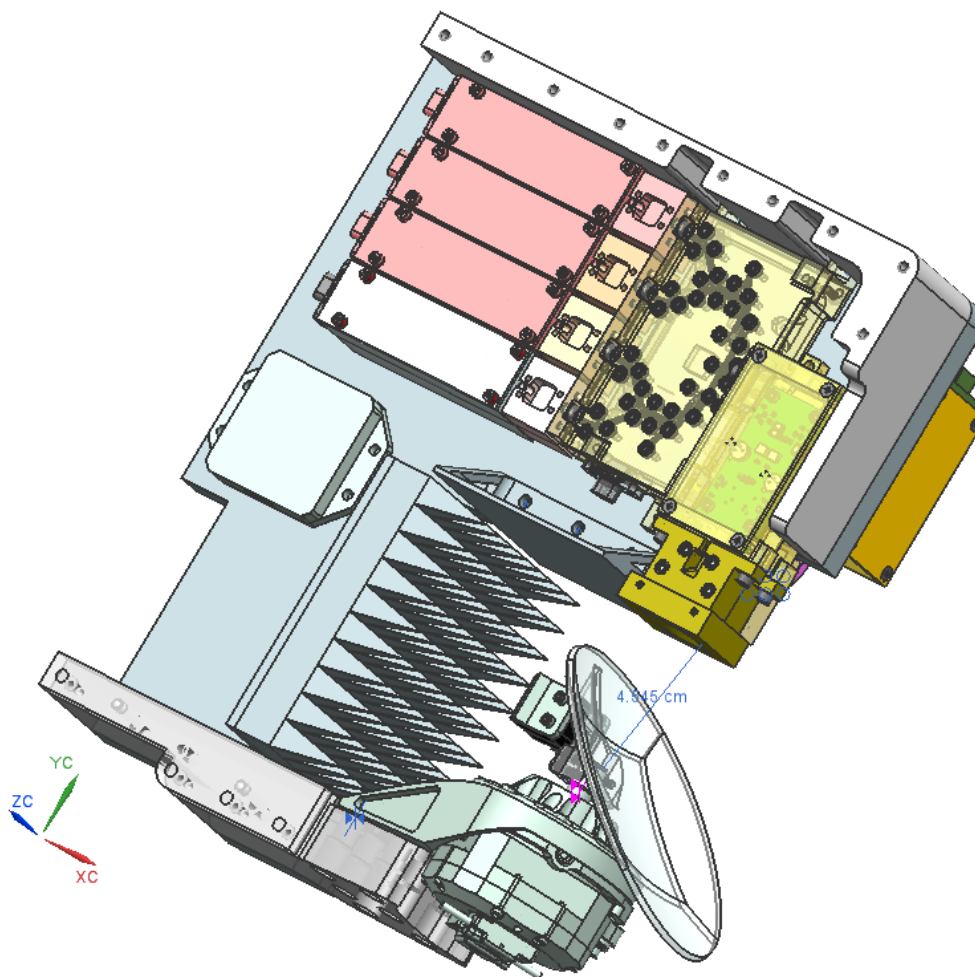
- Instrument HRCR/Pre-ship held July 18, 2017
- Flight TEMPEST-D instrument successfully integrated in flight spacecraft bus in Sept. 2017.
- Spacecraft vibration, thermal balance and thermal vacuum testing completed (including instrument calibration) in Jan. 2018.
- Due to FCC licensing issue, titanium standoffs replaced with aluminum in Feb. 2018.
- Workmanship vibration penalty testing performed on Feb 22, 2018.
- Thermal balance penalty testing performed again from Feb. 27 to Mar. 2, 2018.
- Total Payload operating hours (including at JPL and BCT) is ~550 hours
  - ~250 hours at JPL and ~300 hours at BCT.
- Instrument has been tested, calibrated and ready to fly

# Block Diagram: Direct-Detection Approach

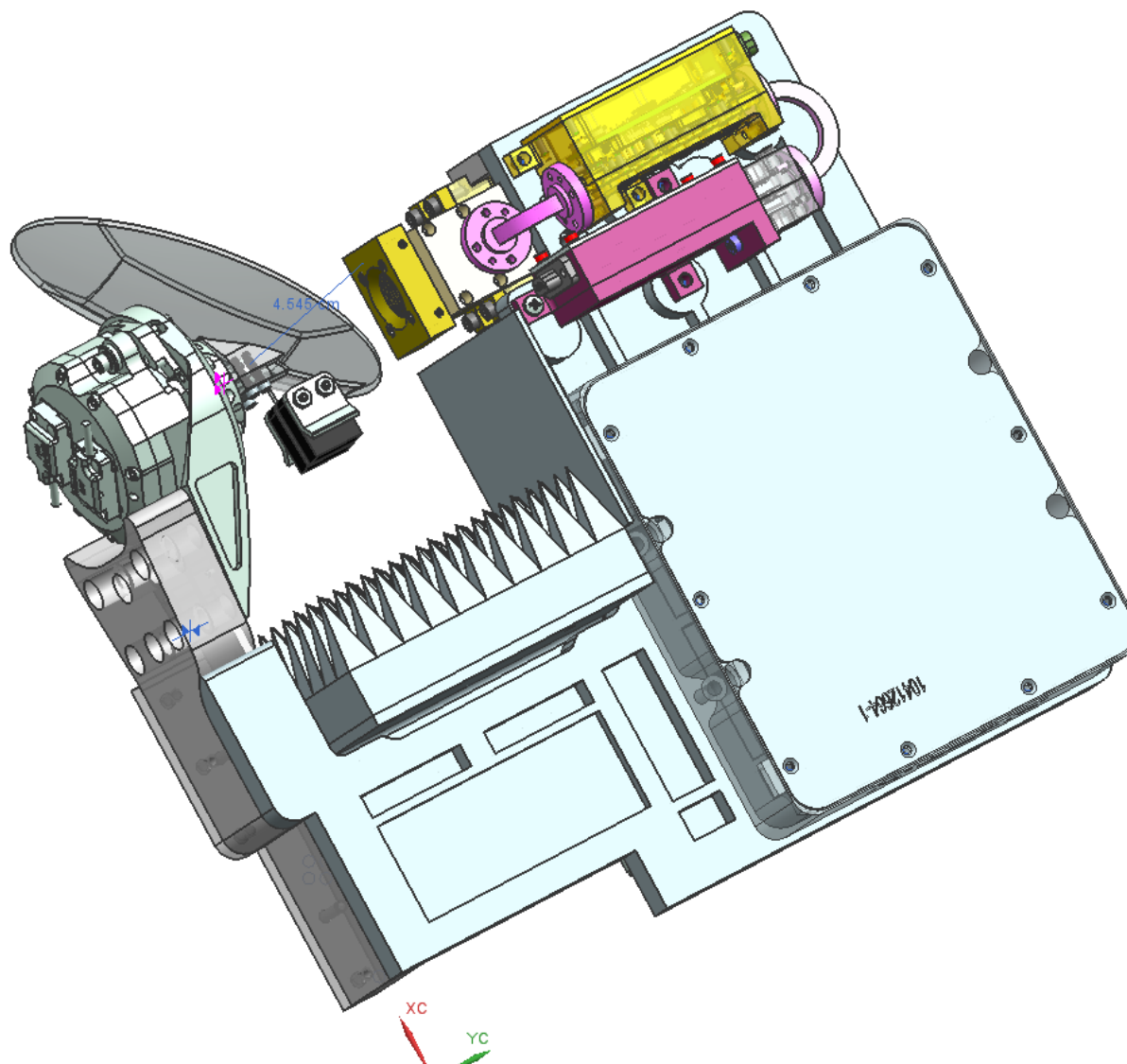


Direct Detection	Voltage (V)	Current (A)	CBE Power (W) Direct-Detection
Spin Mechanism	8	0.09	0.72
RF-Front End 89 GHz	5	0.1	0.5
RF-Front End 182 GHz	5	0.15	0.75
Back-end 89 GHz (includes video board)	5	0.025	0.125
Back-end 182 GHz (includes video board)	5	0.1	0.5
FPGA + ADC	5	0.25	1.25
<b>Total</b>			<b>3.8</b>

# Instrument CAD

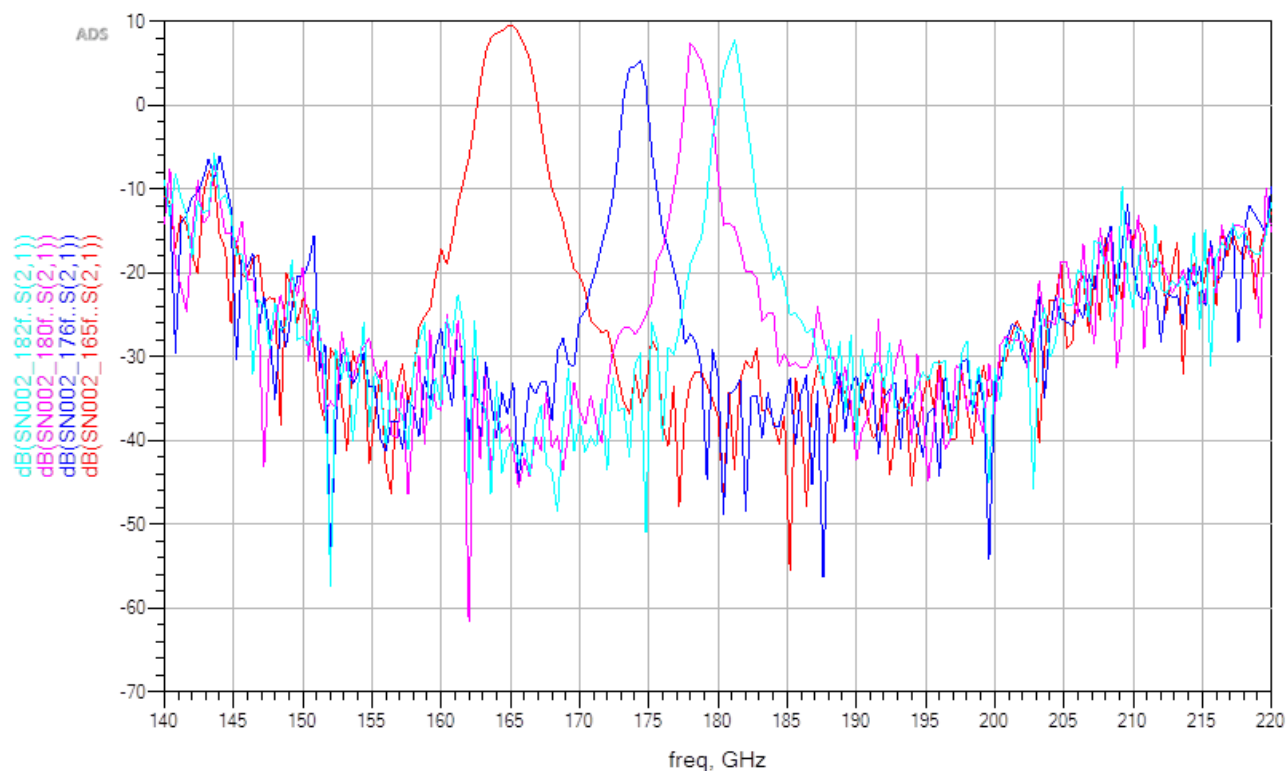


# Instrument CAD



Trimetric WORK

# FM Filterbank Data

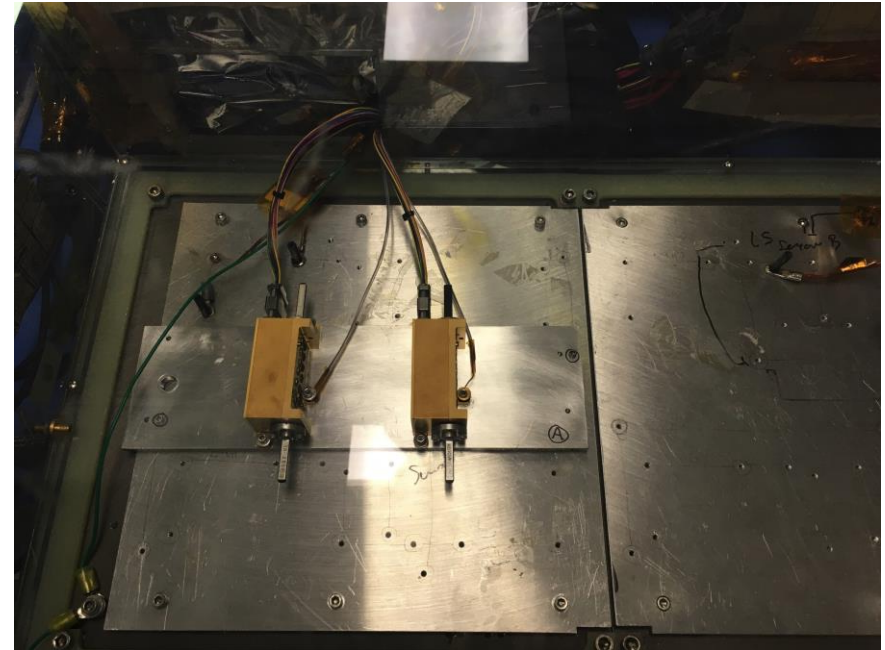
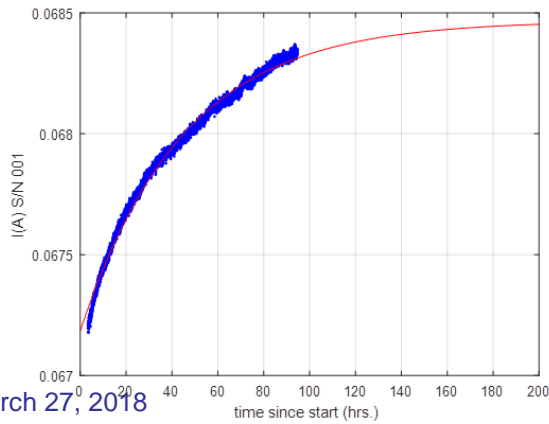
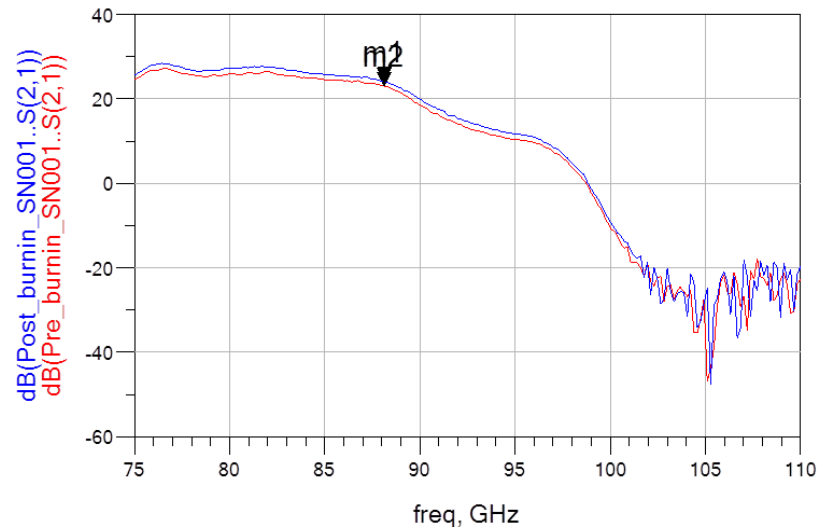


Center Frequency (GHz)	Noise Bandwidth (GHz)
163.9	4.071
175.2	1.901
178.3	1.986
181.1	1.908

# 89 GHz Receiver Burn-in

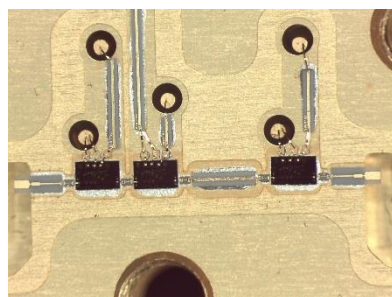
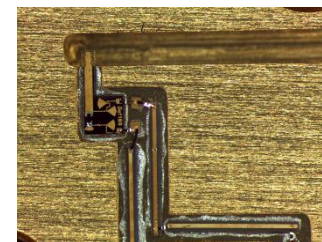
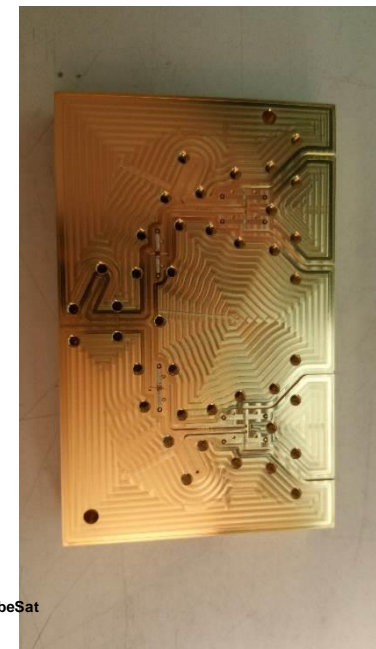
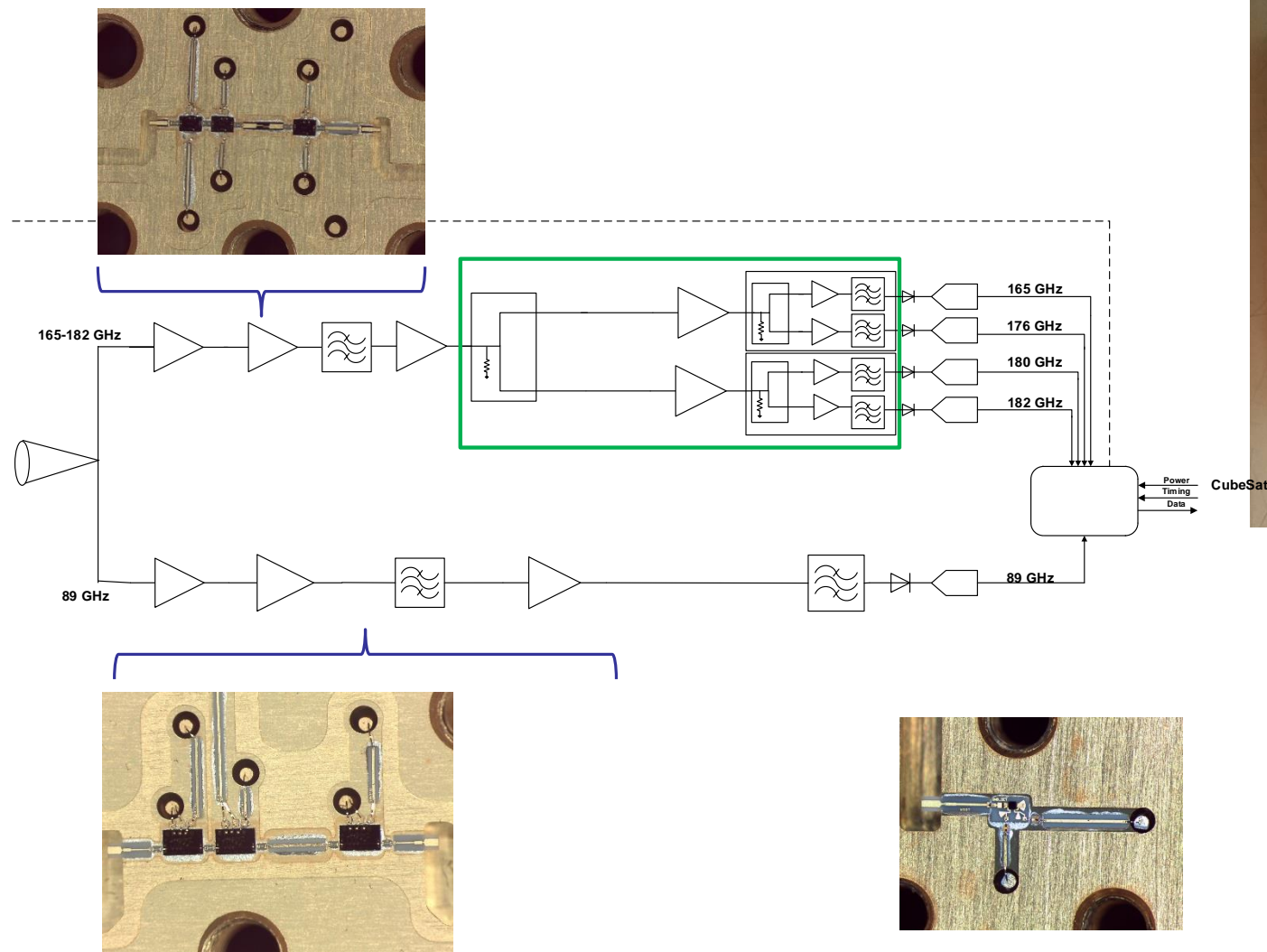
m2  
freq=88.13GHz  
dB(Pre\_burnin\_SN001..S(2,1))=23.025

m1  
freq=88.13GHz  
dB(Post\_burnin\_SN001..S(2,1))=24.096

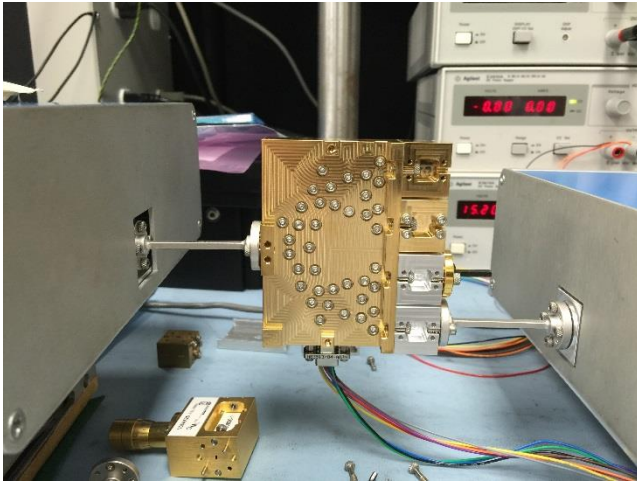


# RF Front-End

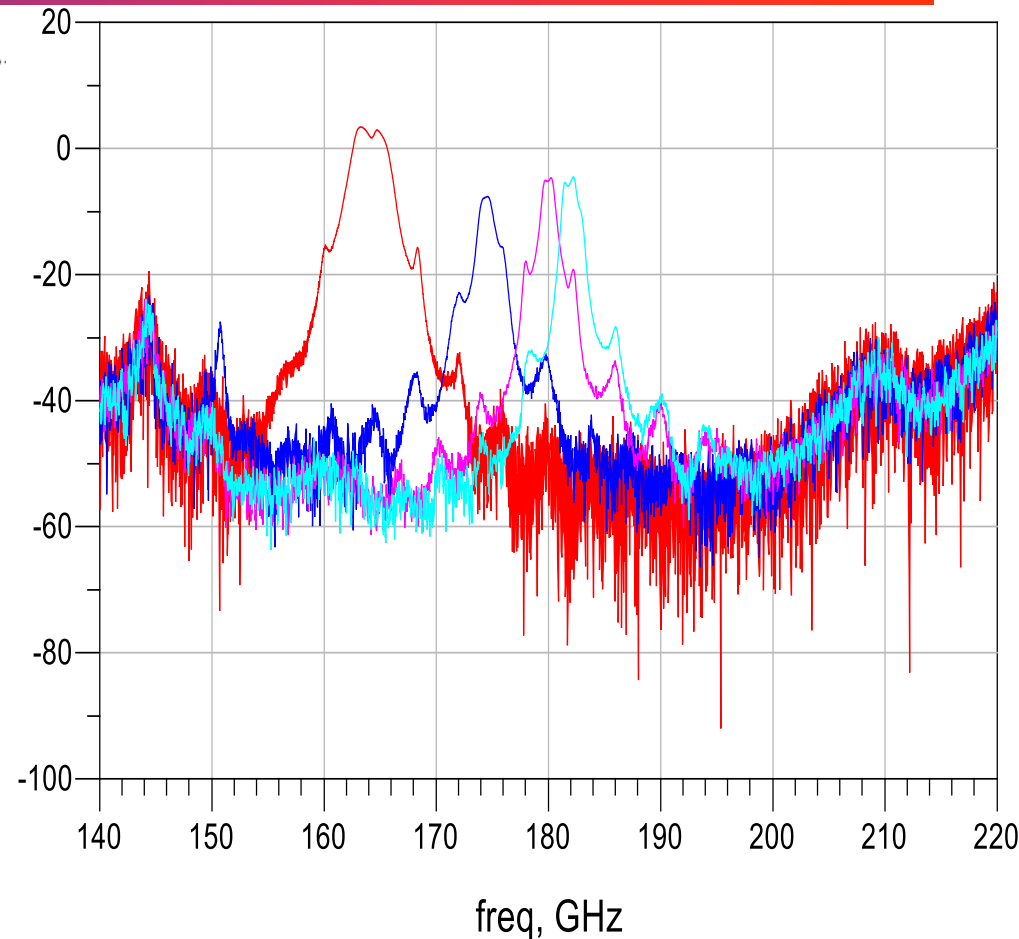
## Direct-Detection Approach



# Prototype Power Divider



dB(pdfil182..S(2,1))  
dB(pdfil180..S(2,1))  
dB(pdfil176..S(2,1))  
dB(pdfil165..S(2,1))



Eqn  $fc1 = \text{center\_freq}(\text{db}(\text{pdfil165}..S21), 3)$

Eqn  $fc2 = \text{center\_freq}(\text{db}(\text{pdfil176}..S21), 3)$

Eqn  $fc3 = \text{center\_freq}(\text{db}(\text{pdfil180}..S21), 3)$

Eqn  $fc4 = \text{center\_freq}(\text{db}(\text{pdfil182}..S21), 3)$

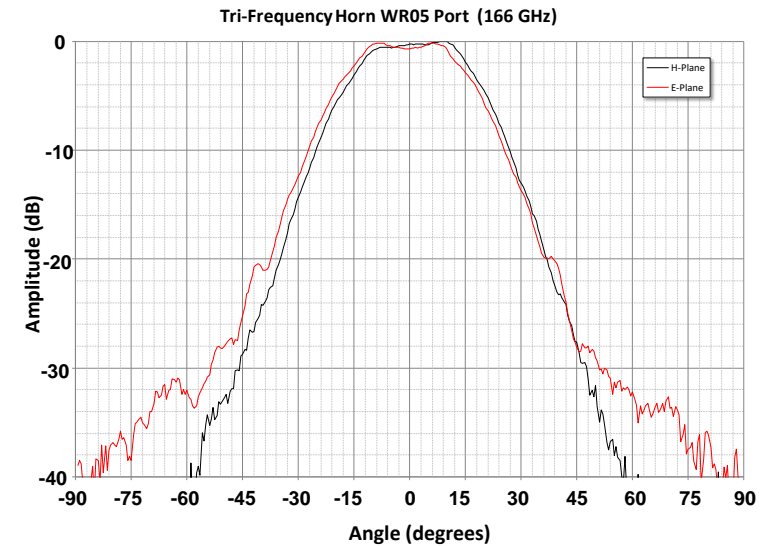
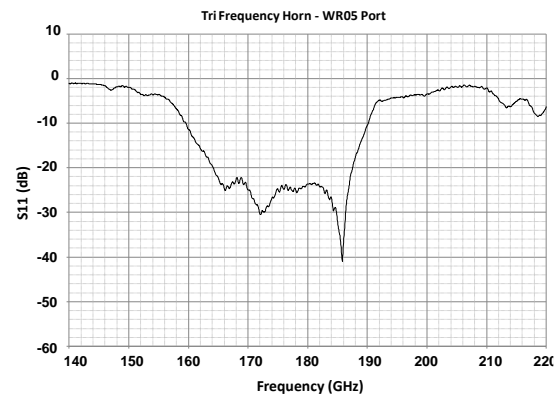
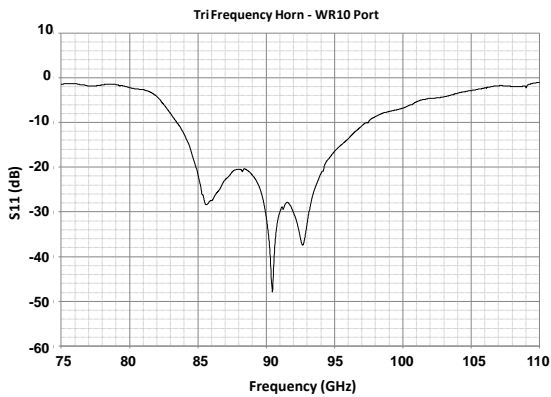
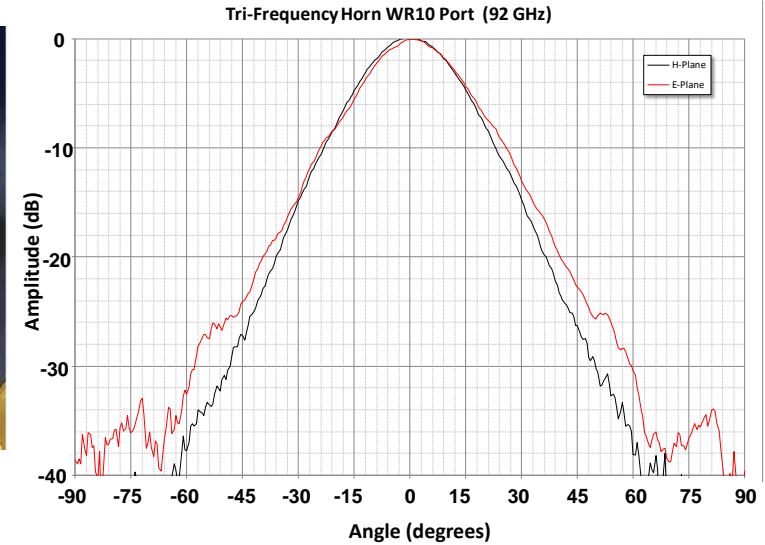
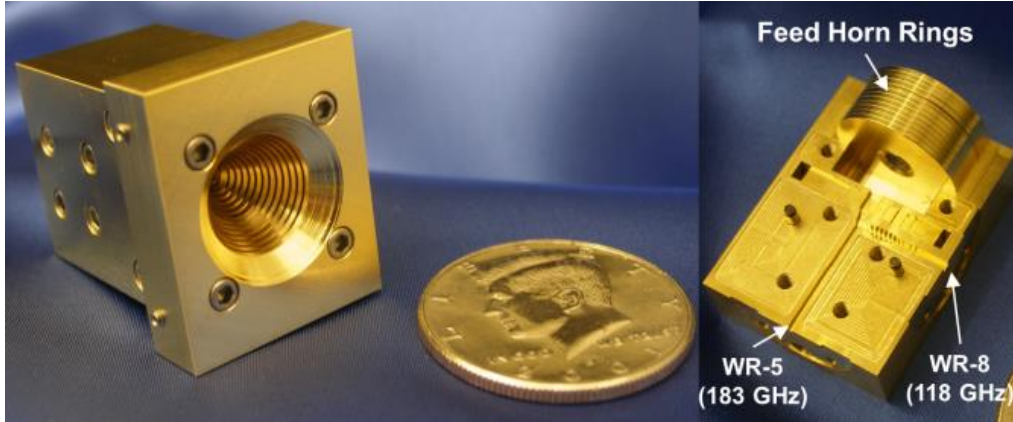
fcx = measured center frequency (GHz)

NBx = measured noise bandwidth (GHz)

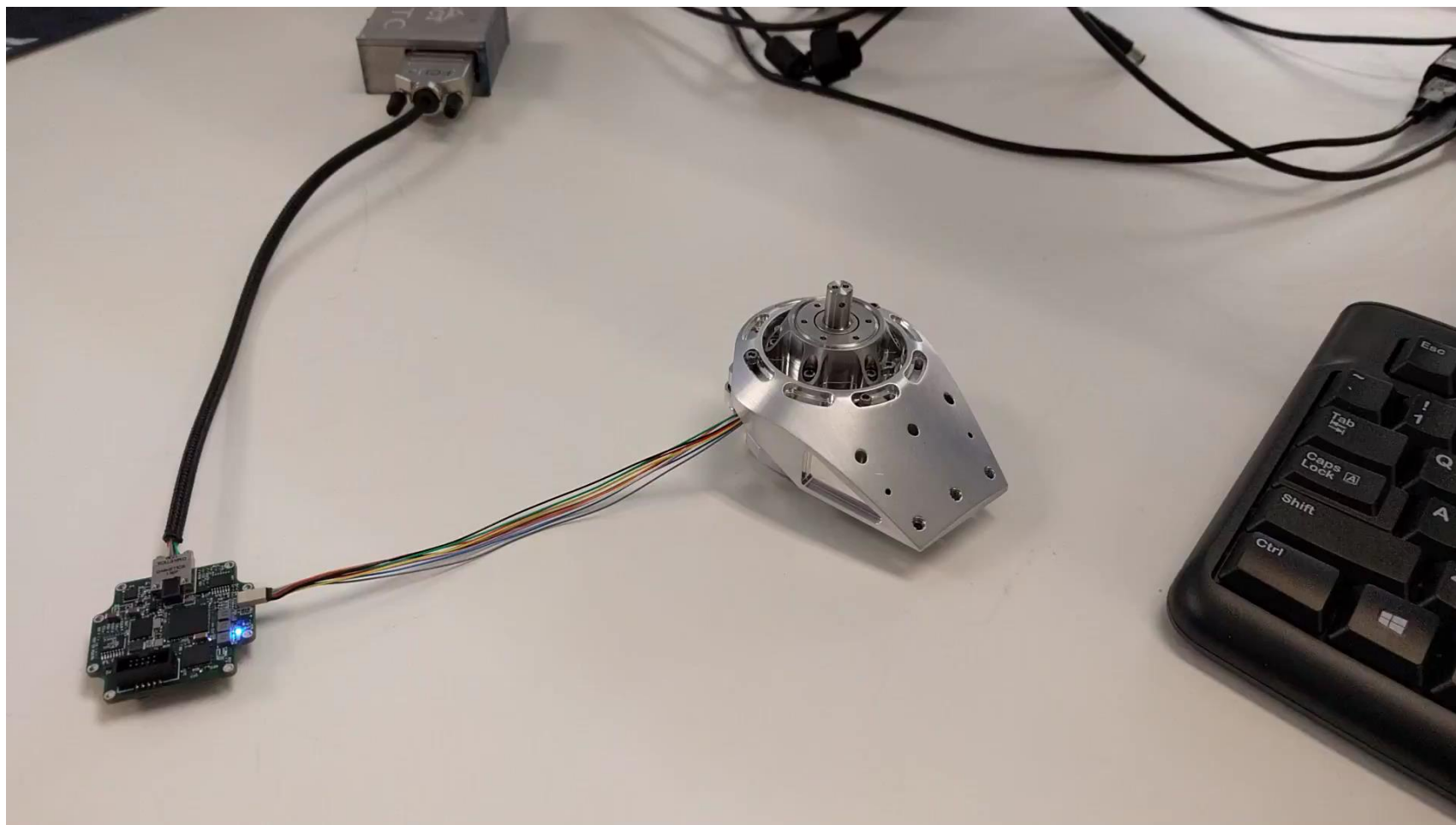


NB1	NB2	NB3	NB4	fc1	fc2	fc3	fc4
3.911	2.320	1.848	1.989	1.641E11	1.744E11	1.800E11	1.819E11

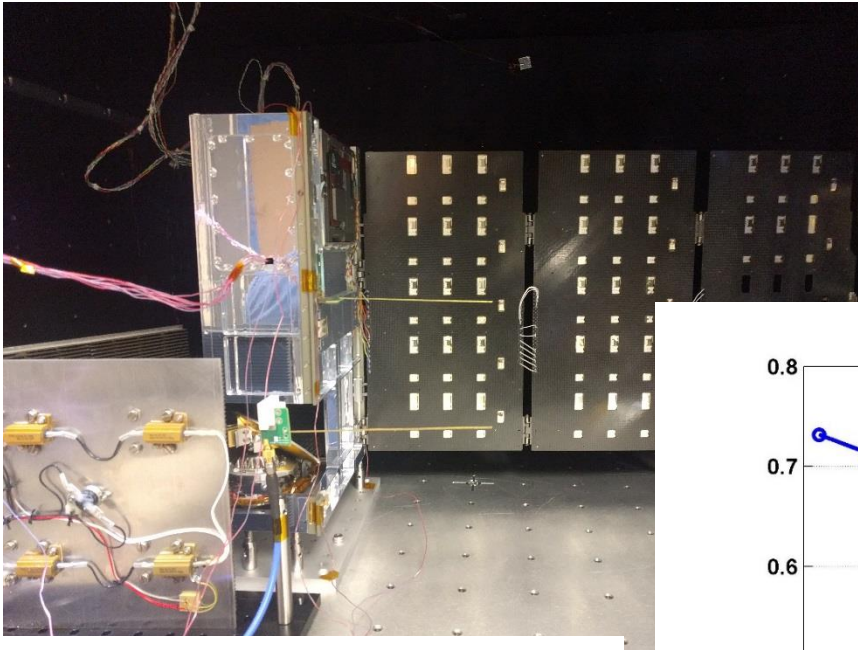
# Feedhorn: Measured Patterns



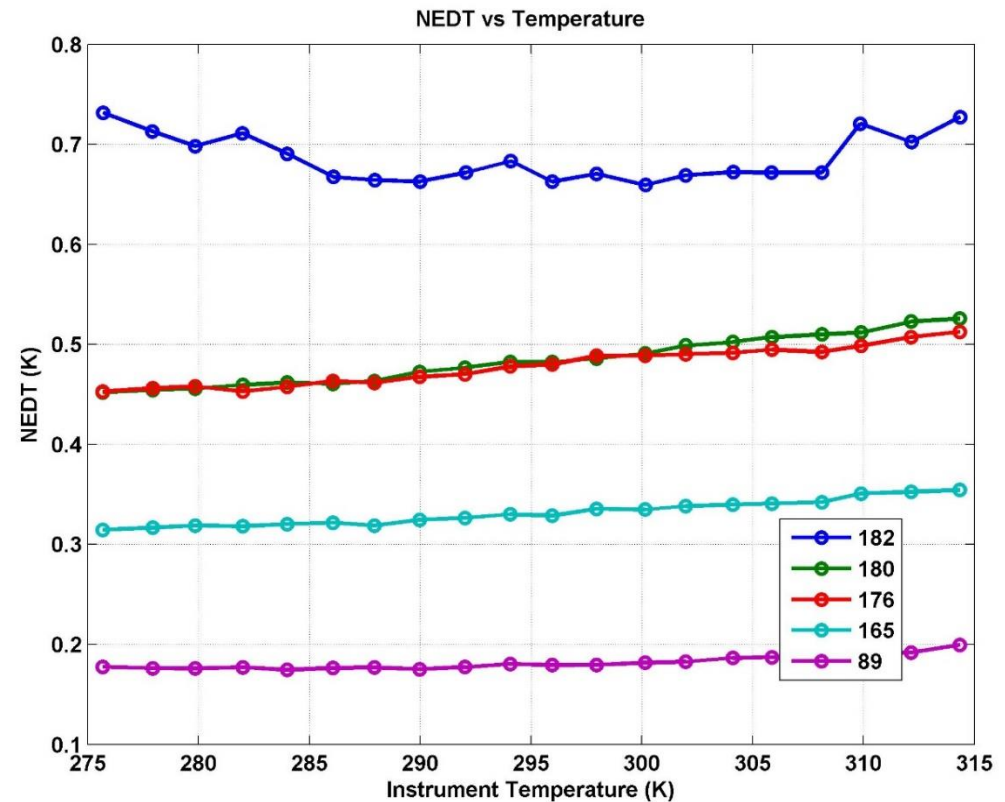
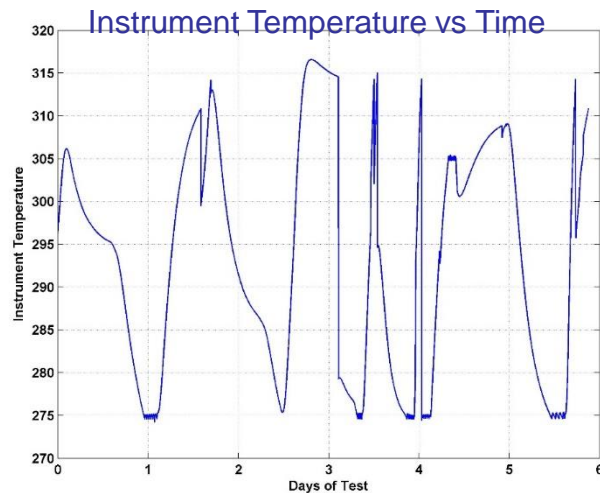
# Scan Mechanism



# Instrument Performance during Thermal Vacuum Testing (Jan. 2018)



Instrument NeDT  
Requirement  $< 1.4$  K



# Roof Testing for Beam pattern Characterization

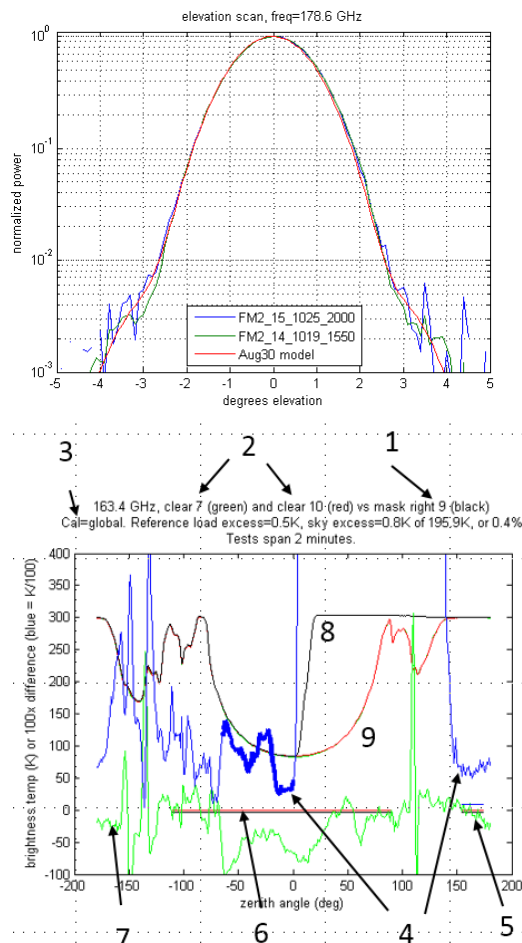
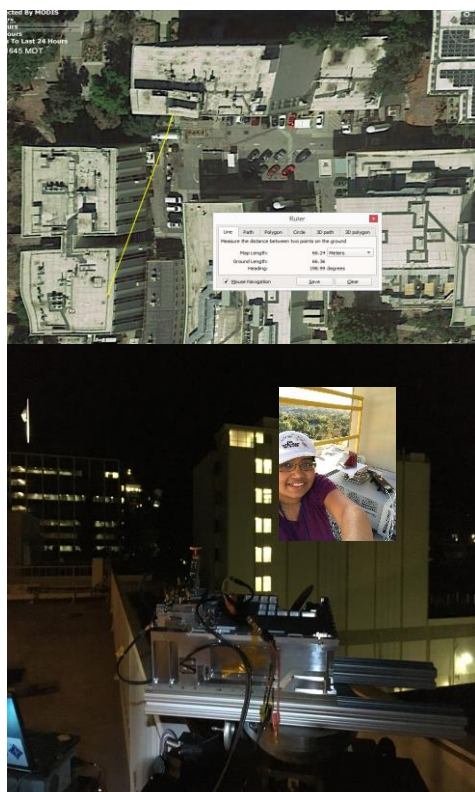
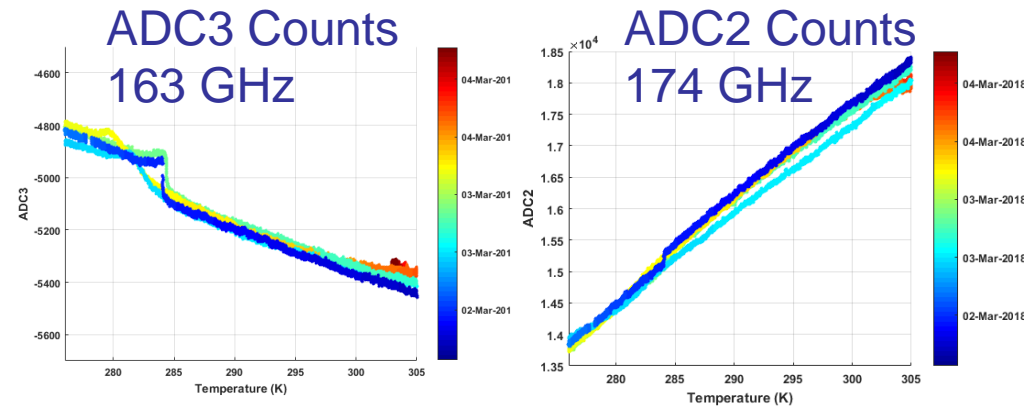


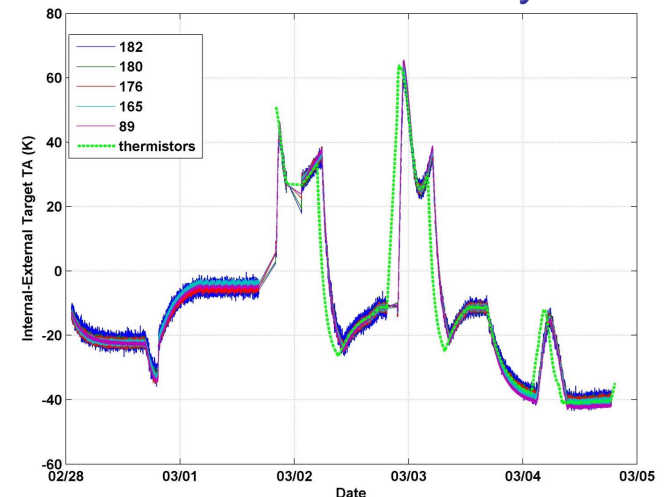
Figure 7: Explanation of composite plots: 1) main test name and sequence number; 2) reference test and number used for comparison (when two tests are listed the average of the two are used as the reference); 3) calibration method (either “global” or “scan/scan referenced”); 4) blue curve is 100 times the difference between test and reference (e.g. 100 K means 1 Kelvin difference), and the heavy blue curve highlights the region where the “sky excess” temperature is evaluated; 5) marks the region where the calibration target occurs; 6) marks the primary observation window (which is notably asymmetric, given the extra field of view to the left, as in Figure 1); 7) the green curve is 100x the difference between the two reference scans, and serves to show in this example that the reference sky background temperatures changed significantly during the tests, as compared with the primary result (blue curve).

# PFR #62545 (Red Flag)

- Gain hysteresis observed in two out of five channels during penalty TVAC test at the S/C level after the Titanium standoff swap out with Aluminum.
- Gain computed during final BCT test when both external and internal targets at plateaus.
- No change to NEDT
- Gain changes by ~3% (0.1dB) before and after shift, tracked by calibration load for the affected channel.
- Calibrated antenna temperature (TA) computed over test shows that the radiometer external calibration allows us to calibrate out the transition and this has no impact on the calibrated TA.
- No root cause identified, but risk deemed acceptable by PI and PM – see attached package



## Calibrated TA resilient to any transitions

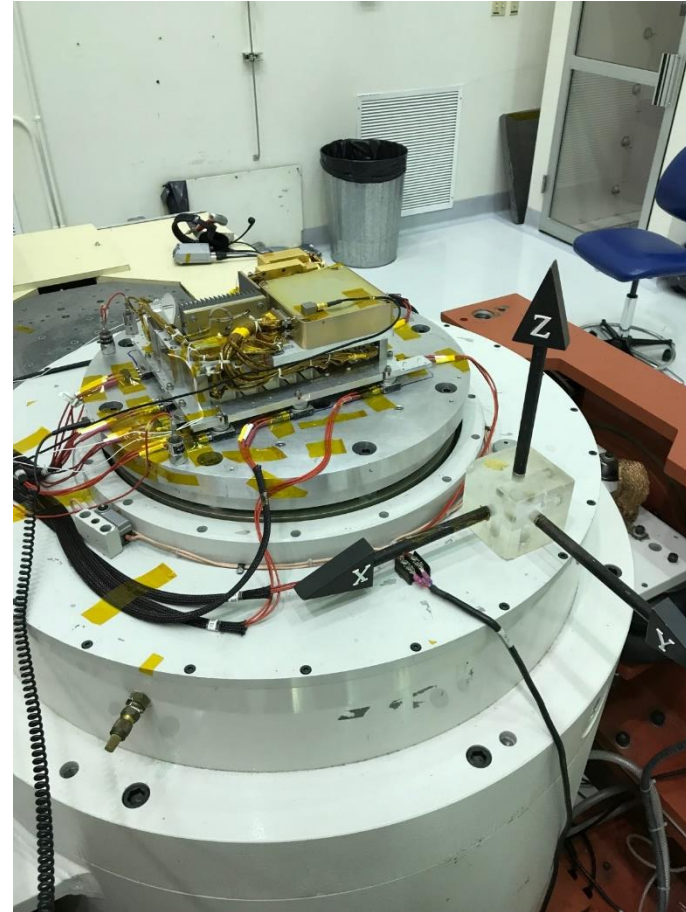


# Spare TEMPEST-D Instrument



Spare TEMPEST-D instrument was tested in the thermal vacuum chamber at JPL from -25 °C to +60 °C (three ramps).

- Spare currently at JPL and needs swap out of the Ti standoffs.



Spare TEMPEST-D instrument was vibration tested at JPL in all three axes to NASA GEVS protoflight levels of 10 g-rms for 1 minute each

# Key Radiometer Level 3 Requirements (1 of 2)

Title	Shall Statement	L1 Parents	Verification Approach	Compliance												
Measurement	<p>The Radiometer shall have at least 5 channels at distinct sideband frequencies between 89 and 183 GHz with center frequencies and bandwidth as defined in table below.</p> <table><tr><th>Center Frequency (GHz)</th><th>Bandwidth (GHz)</th></tr><tr><td>89 ± 2</td><td>4 ± 2</td></tr><tr><td>165 ± 2</td><td>3 ± 1</td></tr><tr><td>176 ± 2</td><td>2 ± 0.5</td></tr><tr><td>180 ± 2</td><td>2 ± 0.5</td></tr><tr><td>182 ± 2</td><td>2 ± 0.5</td></tr></table>	Center Frequency (GHz)	Bandwidth (GHz)	89 ± 2	4 ± 2	165 ± 2	3 ± 1	176 ± 2	2 ± 0.5	180 ± 2	2 ± 0.5	182 ± 2	2 ± 0.5	L1- 3.1.3.	VNA Test	C
Center Frequency (GHz)	Bandwidth (GHz)															
89 ± 2	4 ± 2															
165 ± 2	3 ± 1															
176 ± 2	2 ± 0.5															
180 ± 2	2 ± 0.5															
182 ± 2	2 ± 0.5															
Precision	<p>The Radiometer shall meet the error allocations listed in Table below.</p> <p>PLEASE SEE NEXT SET OF SLIDES</p>	<p>L1- 3.1.3</p> <p>This assumes 1.4 K instrument error for the two instruments being compared.</p>	Radiometric hot-cold test	C												
Accuracy	<p>The Radiometer shall meet the error allocations listed in Table below.</p> <p>PLEASE SEE NEXT SET OF SLIDES</p>	L1- 3.1.4	Radiometric hot-cold test thermal vacuum	C												

# Key Radiometer Level 3 Requirements (2 of 2)

Title	Shall Statement	L1 Parents	Verification Approach	Compliance
<b>Mass</b>	The Radiometer shall weigh less than 4 kg.	<b>L1-3.1.1</b>	Measurement	<b>C</b>
<b>Volume</b>	The Radiometer shall occupy an envelope less than 30 x 10 x 10 cm.	<b>L1-3.1.1</b>	Measurement	<b>C</b>
<b>Data Rate</b>	The Radiometer shall have a data rate of less than 12 kbps.	<b>L1-3.1.6</b>	Test	<b>C</b>
<b>Antenna</b>	The Radiometer shall have an antenna half power beamwidth (HPBW) shall be less than or equal to $4.3^\circ$	<b>L1-3.1.2</b>	HFSS Analysis and range test	<b>C</b>
<b>Time Accuracy</b>	The Radiometer shall have data time tagged with a maximum error of 1 ms.	<b>L1-3.1.6</b>	test	<b>C</b>

**All L3 requirements have been verified (compliant)**

# Technical Resources Summary

Resource	CBE	Allocation	Margin (Actual)
Radiometer Mass (kg)*	3.75	4.0	6.25%
Radiometer Power (W)	6.0	6.5	8%
Radiometer Data Rate (Kbps)**	10.3	12.3	16%
Radiometer Precision (K)	0.4-0.95	1.4	71-32%
Radiometer Accuracy (K)	3.5	4	13%

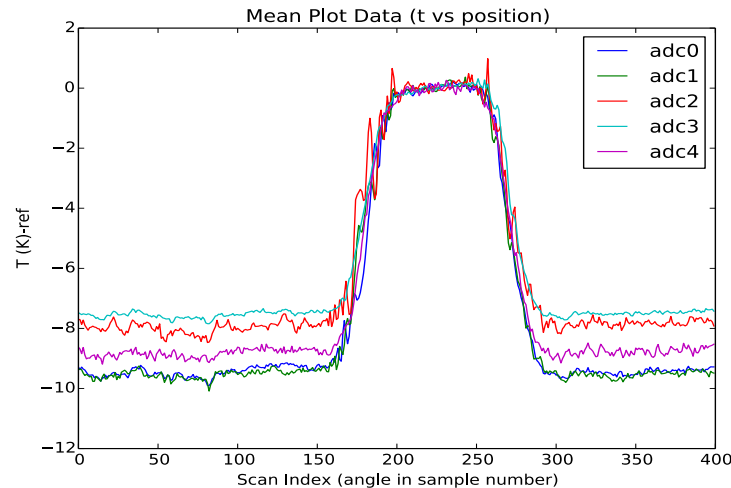
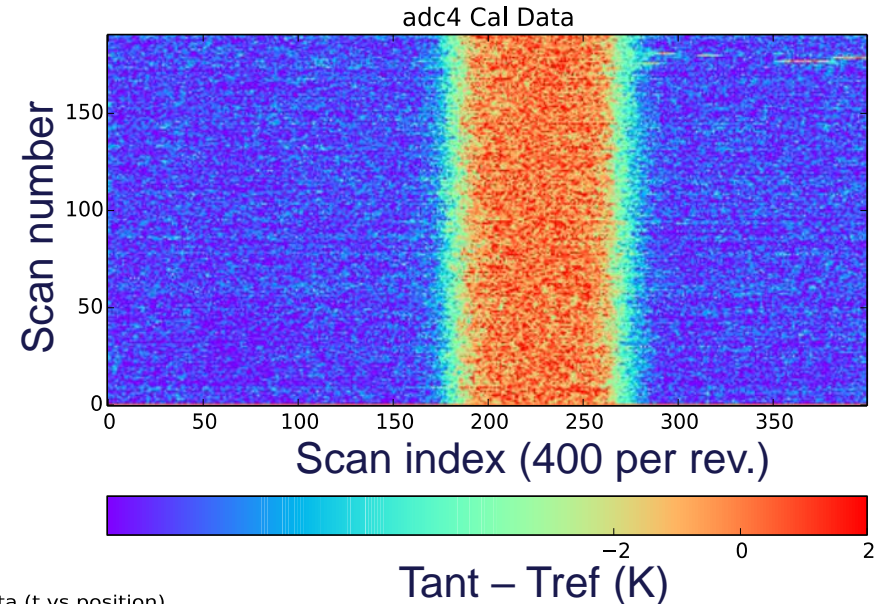
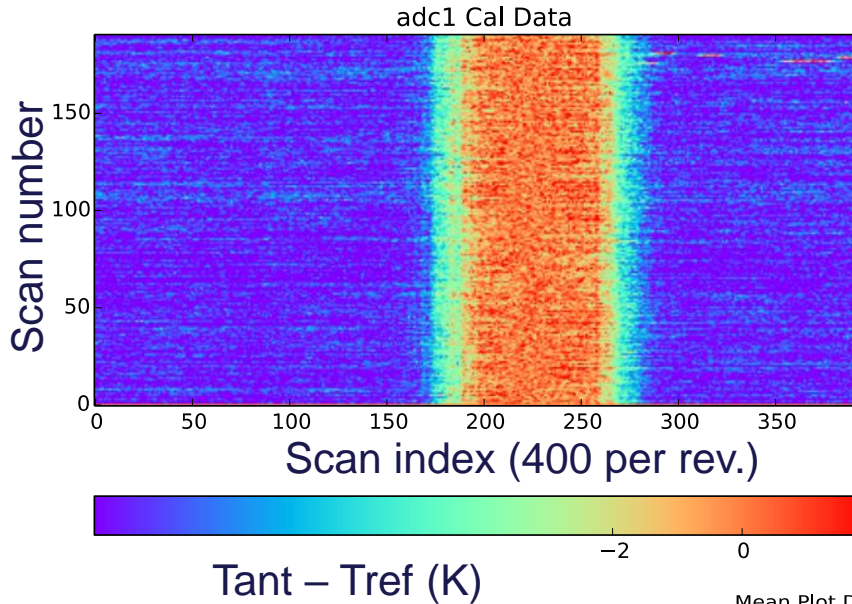
$$MARGIN = 100 \times \frac{Allocation - CBE}{Allocation}$$

\*Change due to titanium standoff replacement with aluminum

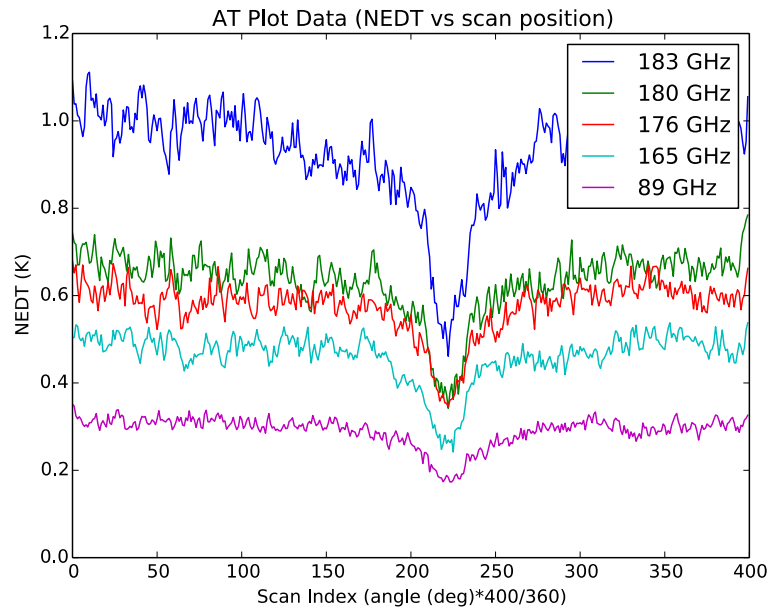
\*\*Includes spacecraft state-of-health telemetry

All excess margin can now be released to the spacecraft.

# Testing Results: EMI Self-Compatibility Tests



# Testing Results: Post-EMI Self-Compatibility Tests

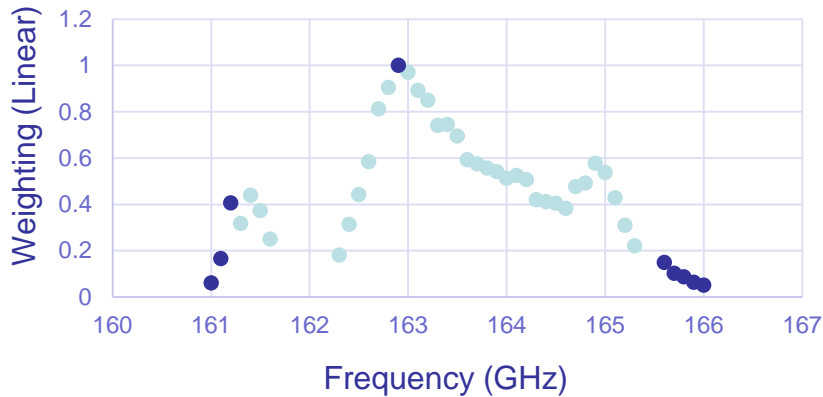


Frequency (GHz)	NEDT (K)	Total Noise Requirement (K)
89	0.3	1.4
164	0.5	1.4
175	0.6	1.4
178	0.7	1.4
181	0.9	1.4

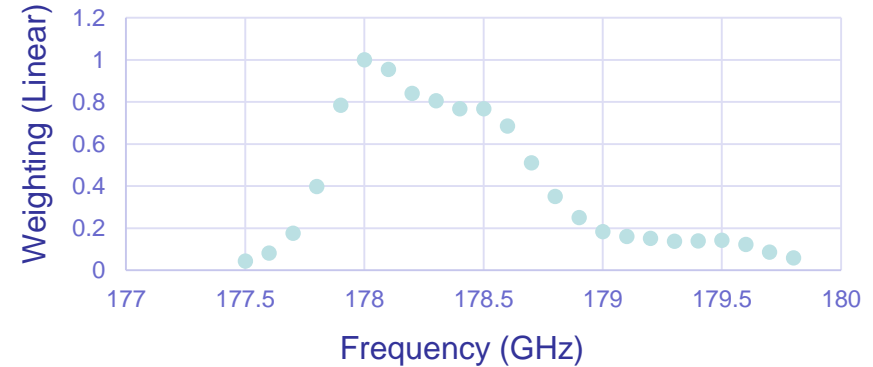
Measured NEDT values meet total noise requirements for all five millimeter-wave radiometer channels.

# Testing Results: End-to-End Receiver Bandpass Responses

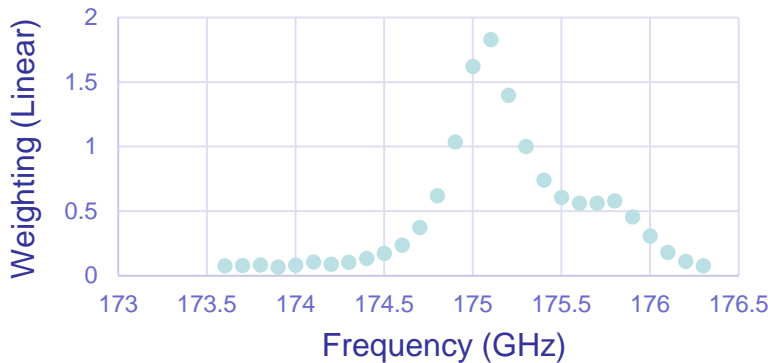
165 GHz Both Sweeps



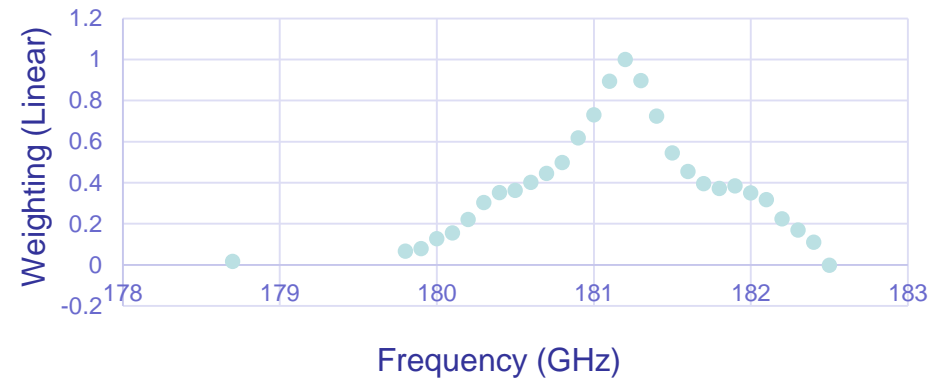
180 GHz Sweep 1



178 GHz Sweep 1



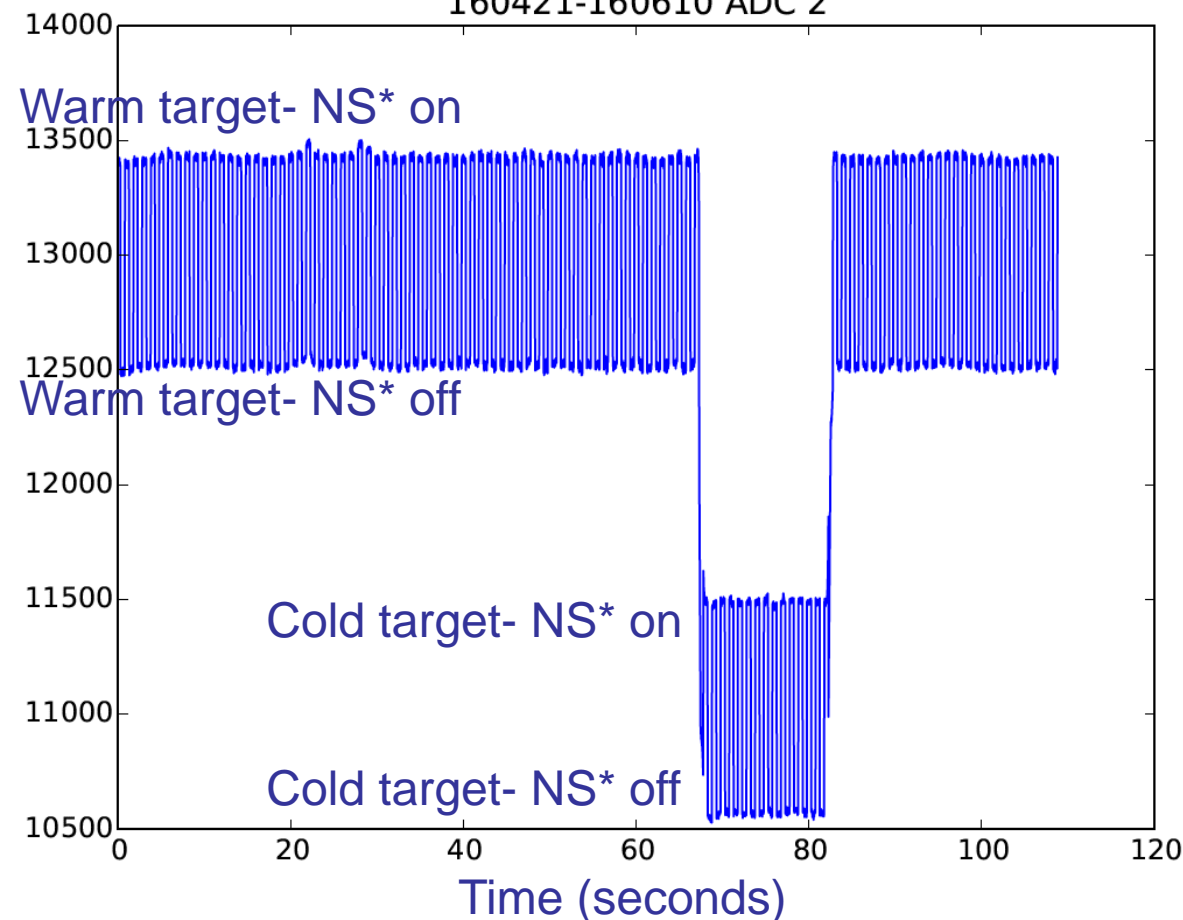
182 GHz Sweep 1



Measured end-to-end receiver bandpass responses will be used as input to validation algorithms.

# Testing Results: Linearity of Flight Model and Flight Spare

FM1 178 GHz Counts- Linearity  
160421-160610 ADC 2



## Flight Model (FM1) QL Results:

182 GHz max non-linearity = 2.67%  
180 GHz max non-linearity = 2.93%  
178 GHz max non-linearity = 2.04%  
165 GHz max non-linearity = 2.90%

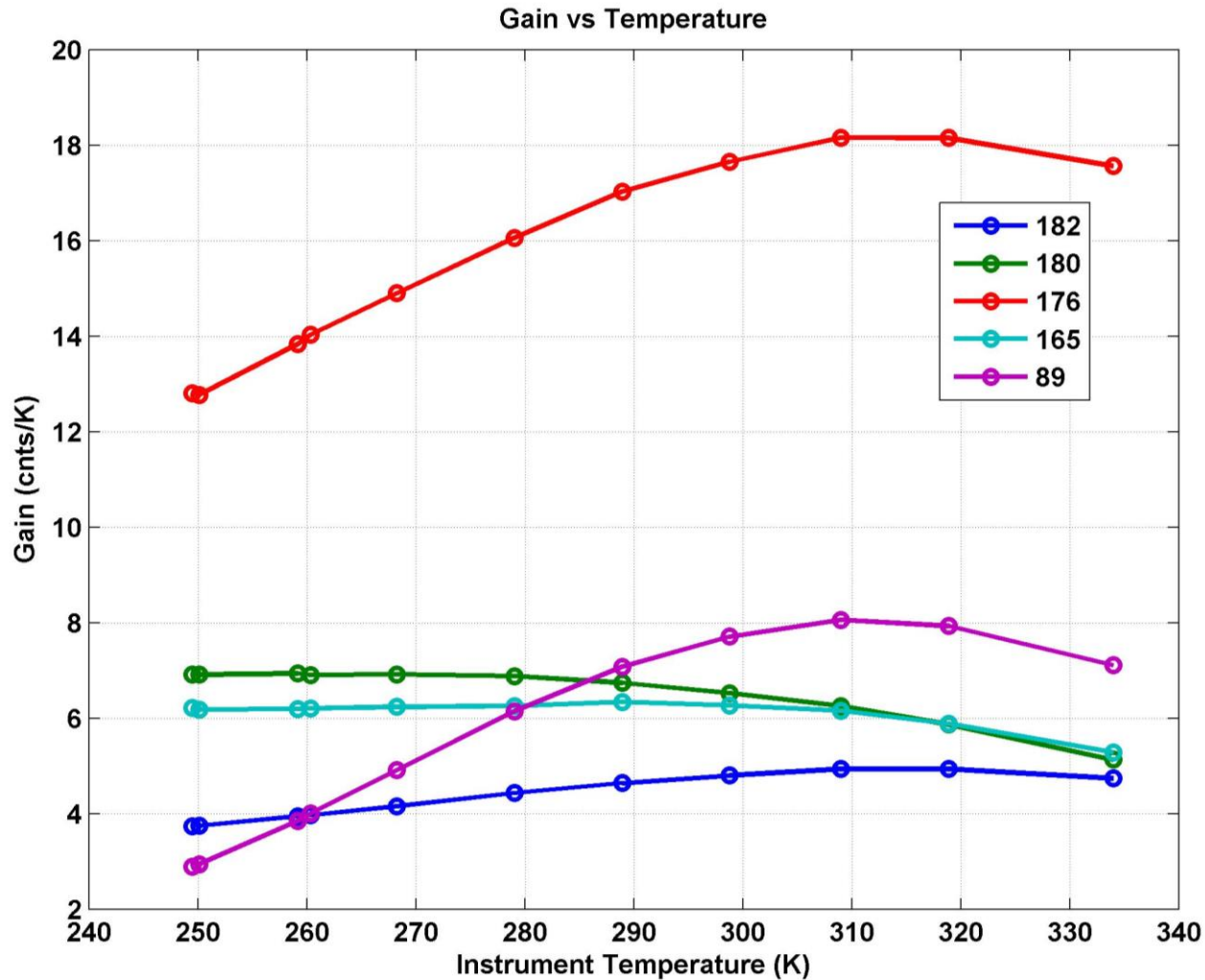
## Flight Spare (FM2) QL Results:

182 GHz max non-linearity = 2.81%  
180 GHz max non-linearity = 2.69%  
178 GHz max non-linearity = 2.73%  
165 GHz max non-linearity = 4.88%

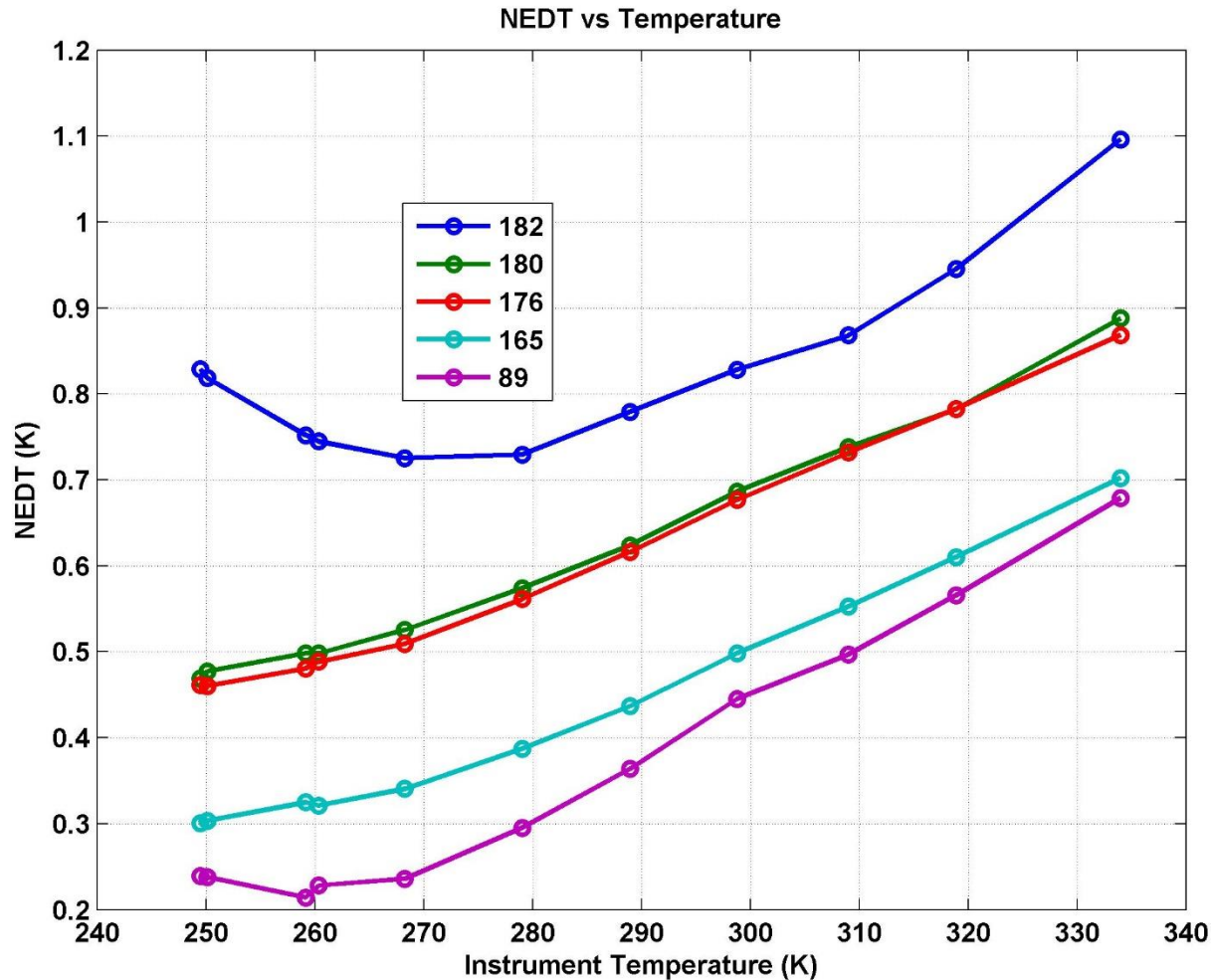
A more complete linearity test was performed, but the results have not yet been analyzed.

\*NS = noise source

# TVAC Results for FM1: Gain vs. Temperature

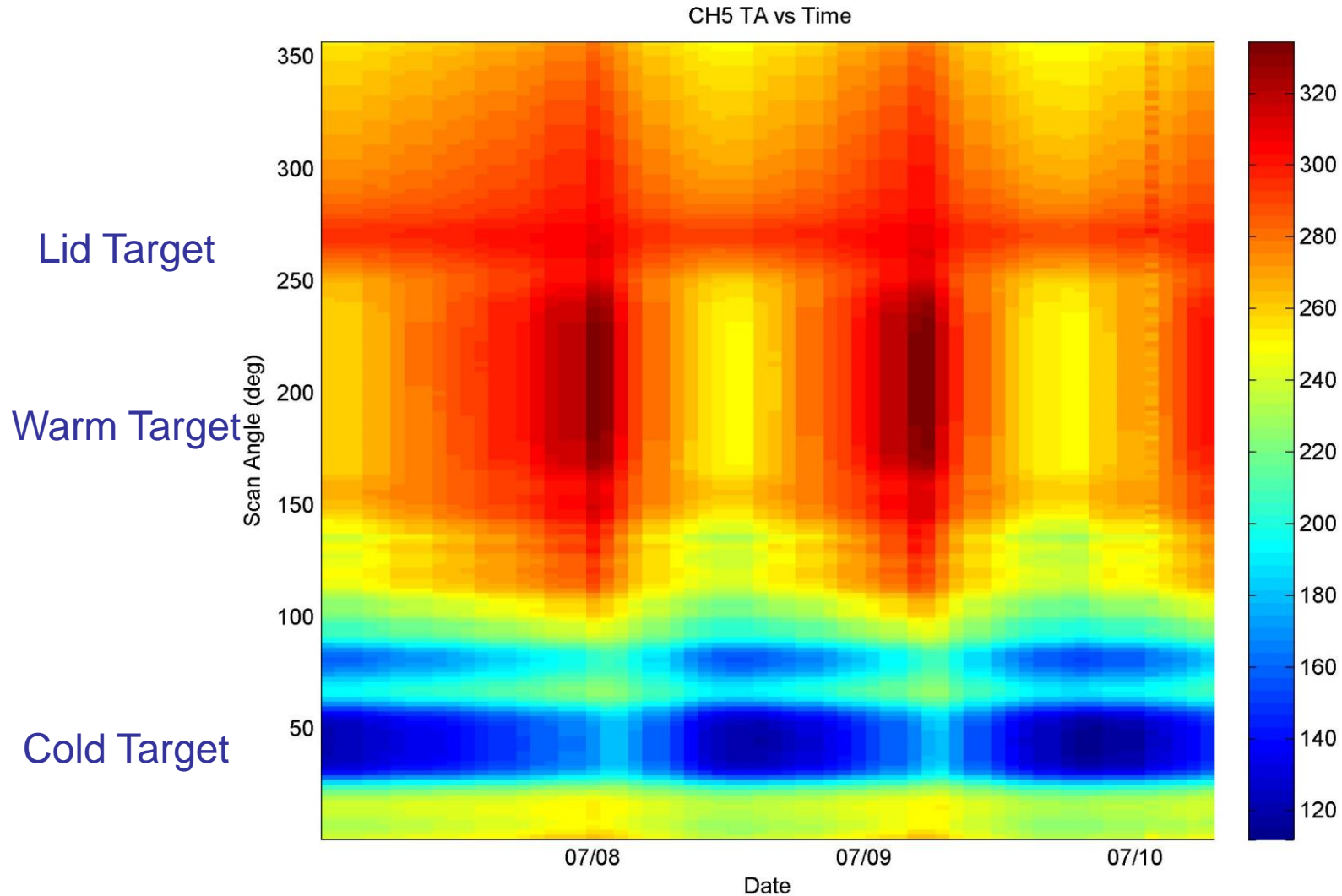


# TVAC Results for FM1: NEDT vs. Temperature



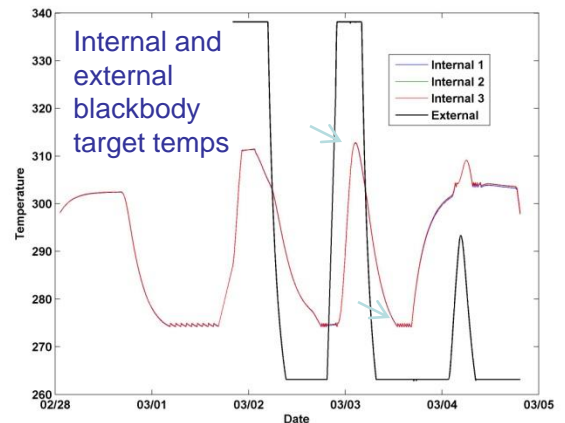
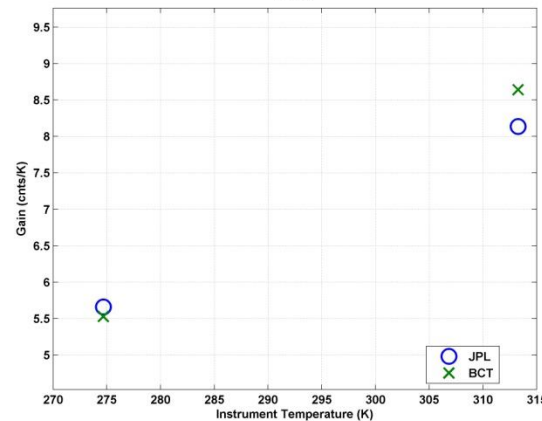
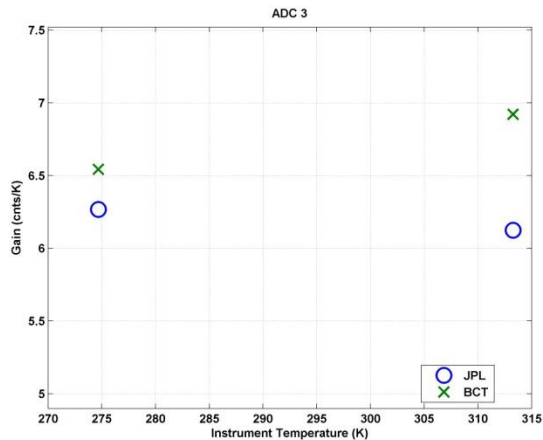
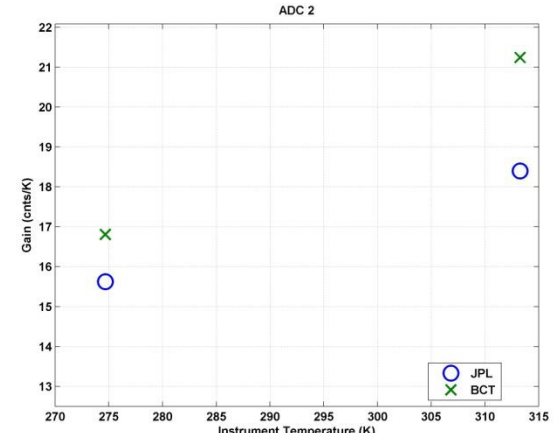
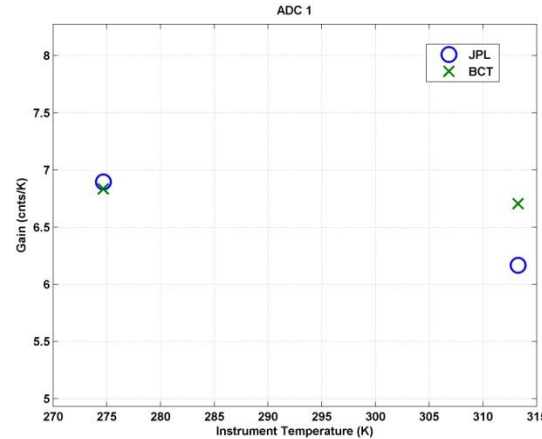
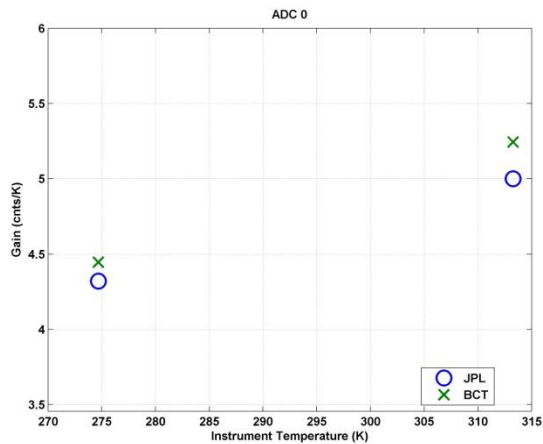
NEDT Measured on cold target, which varies with temperature

# TVAC Results for FM1: 89 GHz Chamber Imagery



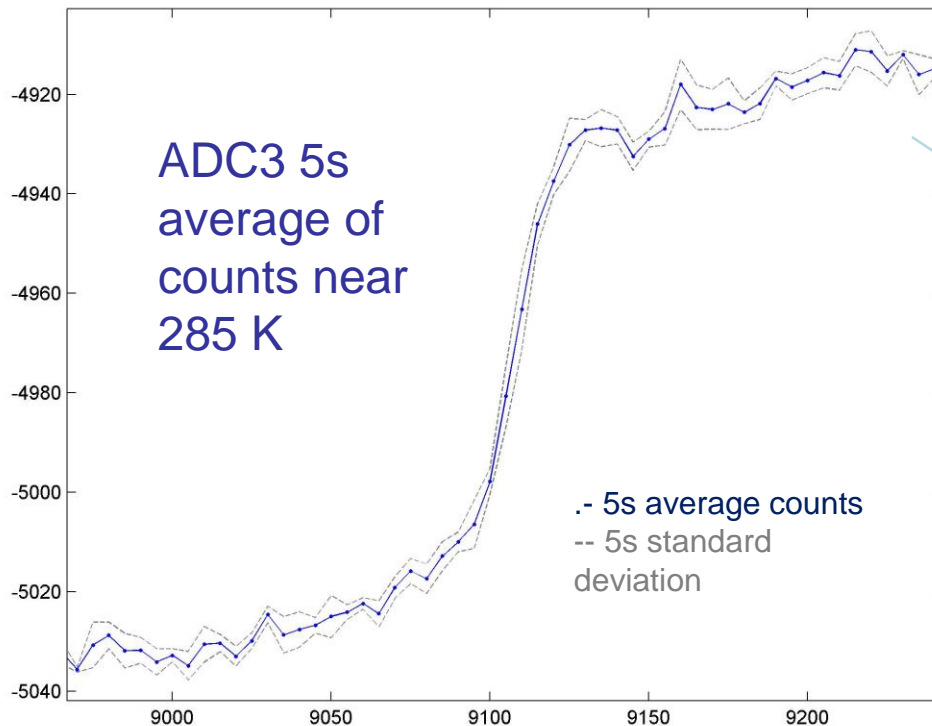
# Gain Comparison

- Gain computed during final BCT test when both external and internal targets at plateaus
- No significant differences in end-to-end gain observed from JPL TVAC test
  - Absolute uncertainty in BCT gain likely at 5% level due to small target temperature difference (20-30K) and 1-2C target temperature knowledge

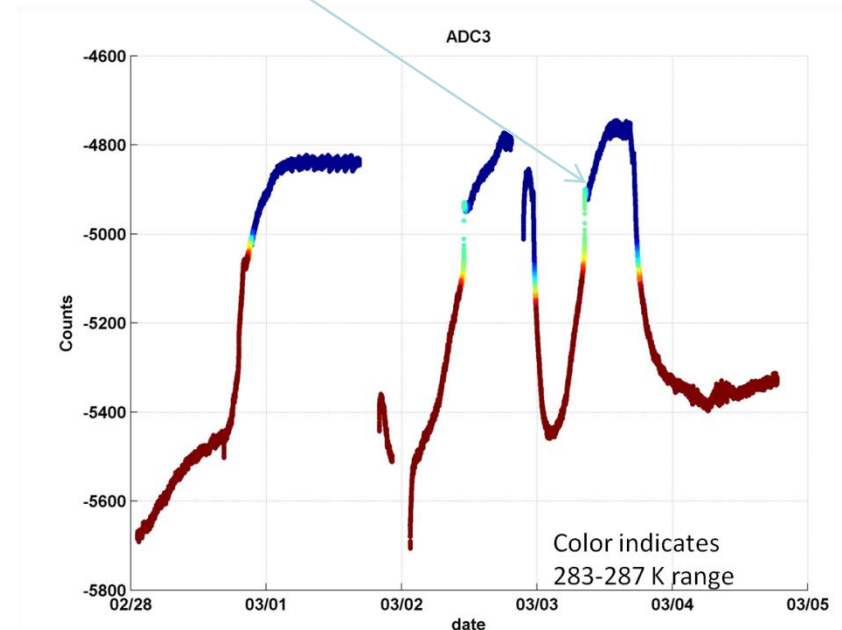


# ADC3 Feature

- ADC3 shows ~100 count change over 30s when cooling through 285K

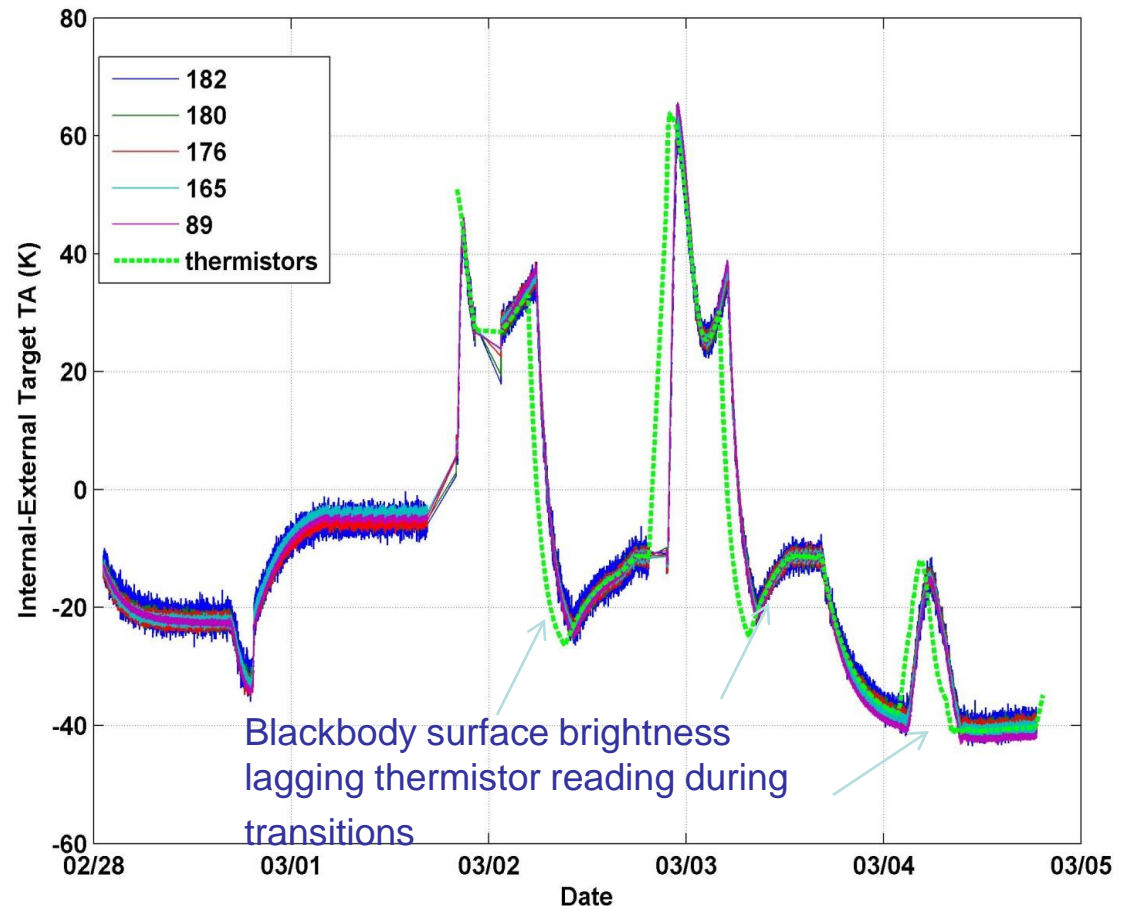


ins consistent throughout



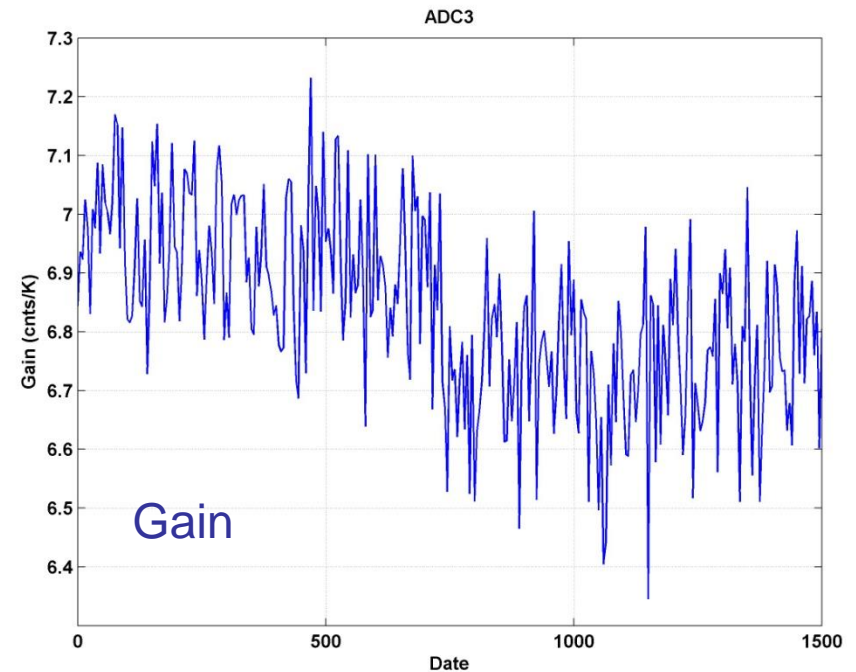
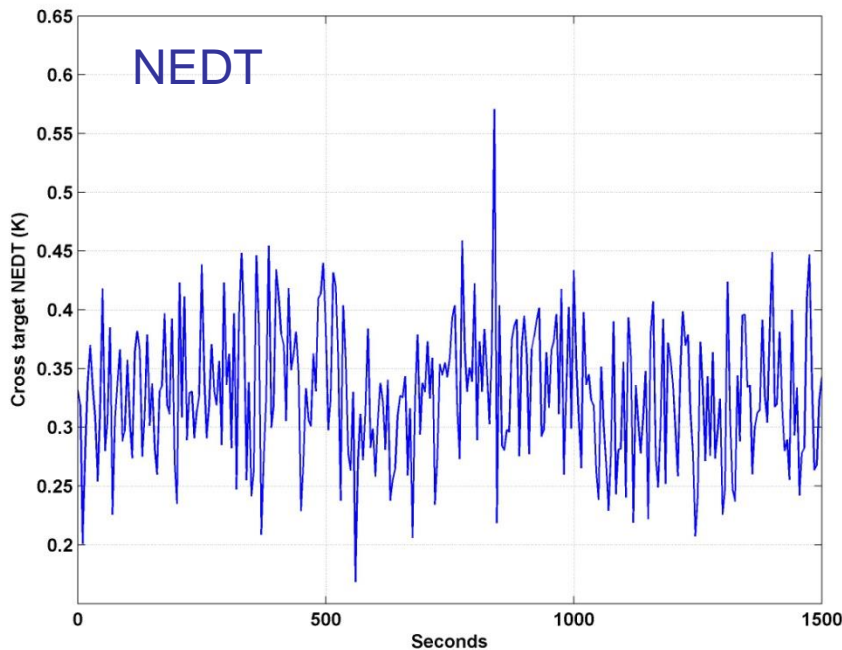
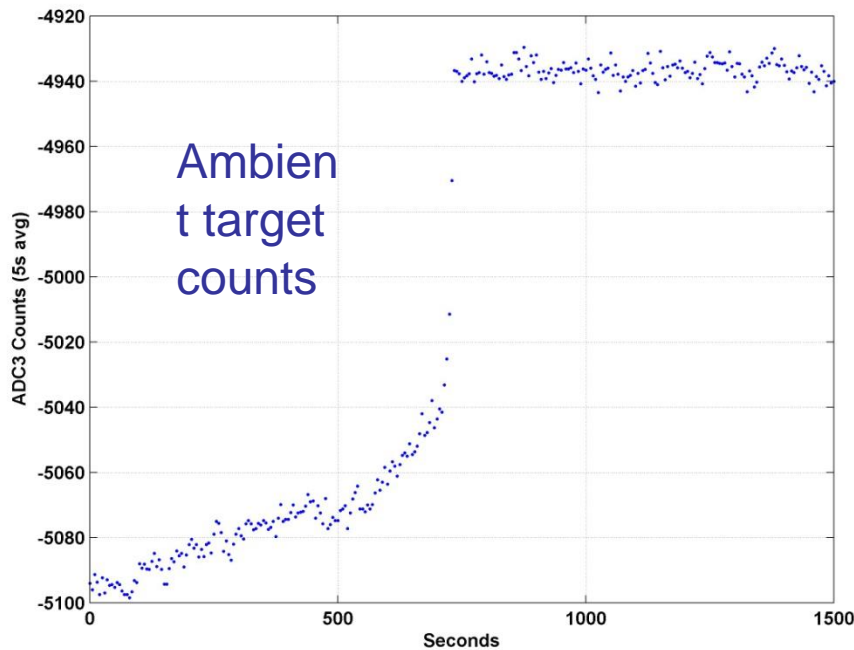
# Antenna Temperature

- Computed internal/external brightness difference for each channel over test
- All channels track difference well, in agreement with measured difference (except during target transitions when thermistor is not tracking brightness of blackbody surface)

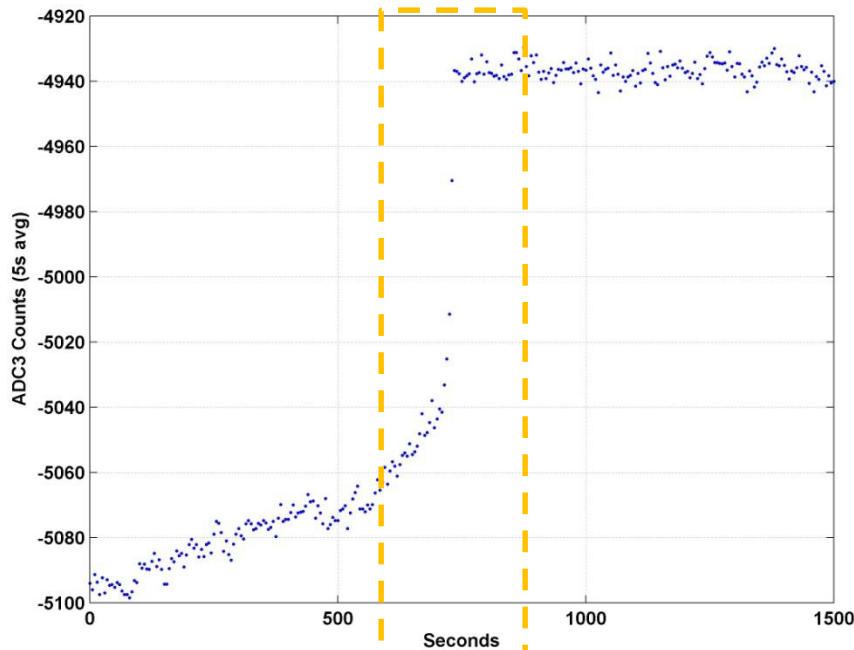


# ADC3 Feature

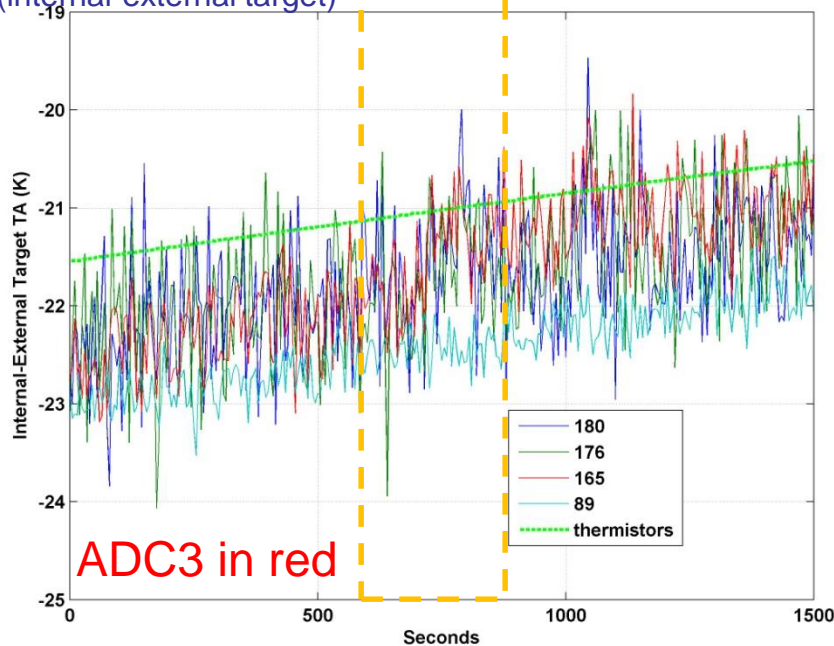
- No change to NEDT
- Gain changes by ~3% (0.1dB) before and after shift, tracked by calibration load



# ADC3 Feature



Antenna temperature  
(internal-external target)



ADC3 in red

- No significant impact on calibrated antenna temperature during ADC3 jump relative to TEMPEST requirement
  - ADC3 TA consistent with other channels during jump

# TVAC Testing: Scanning Mirror Rotating in Vacuum Chamber

